AIN SHAMS UNIVERSITY
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ELECTRONICS AND COMMUNICATIONS ENGINEERING DEPARTMENT

Temperature Compensated CMOS Crystal Oscillators Design

A Thesis

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Submitted by

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

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This dissertation demonstrates the design of a CMOS temperature compensated crystal oscillator. It begins with a brief about crystal oscillators, importance of its frequency stability. Different crystal oscillators' circuit configurations, different types of analyses and performance parameters are discussed.

Next, it presents the different methods used to enhance frequency stability of crystal oscillators by using amplitude control loops and temperature sensors. Then, it presents a modification for pierce crystal oscillator to control its amplitude without using amplitude control loops. The effect of this modification on other crystal oscillator circuit parameters is discussed. The modified pierce crystal oscillator is designed, analyzed, and simulated using CMOS technology.

The dissertation, then, presents the temperature sensor used to compensate the crystal behavior with temperature variation. The temperature sensor circuit is designed, analyzed, and simulated using CMOS technology.

Finally, the whole system is integrated, and simulated. Results are presented and compared to similar work of some other authors.

Key words: TCXO, CMOS, amplitude control, and temperature sensors.

SUMMARY

This dissertation demonstrates the different issues of implementing TCXO in CMOS technology. The dissertation is divided into five chapters organized as follows:

Chapter One: This chapter is an introduction to crystal oscillators' basics, importance of crystal oscillator frequency stability, and parameters.

Chapter Two: In this chapter, the factors that affect crystal oscillator frequency stability are discussed. Different methods used to enhance it are discussed. And, the proposed system architecture is presented

Chapter Three: In this chapter, the new method we implement for amplitude control is presented, explained, and analyzed. The circuit design of the amplitude controlled crystal oscillator in CMOS technology is presented. The main blocks of the amplitude controlled crystal oscillator are analyzed, designed, and simulated.

Chapter Four:

In this chapter, the temperature sensor basics are discussed. The main blocks are analyzed, designed, and simulated.

Chapter Five:

In this chapter, the system integration results are presented. Layout of the complete system architecture is shown.

Finally, the thesis ends by extracting conclusions and stating future work that might be done based on this work.

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CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

a_1	Fundamental Fourier series cosine coefficient
A_1	Coefficient of quartz crystal frequency stability equation
A_2	Coefficient of quartz crystal frequency stability equation
A_3	Coefficient of quartz crystal frequency stability equation
$A(j\omega)$	Transfer function of amplifier circuit
b_1	Fundamental Fourier series sine coefficient
C_0	Shunt capacitance of quartz crystal
C_1	Part of load capacitance
C_2	Part of load capacitance
C_{int}	Integrator capacitor
C_L	Load capacitance
C_m	Motional arm capacitance of quartz crystal
C_{max}	Maximum capacitance
C_{min}	Minimum capacitance
DL	Drive level of quartz crystal
DL_{min}	Minimum drive level of quartz crystal
DL_{max}	Maximum drive level of quartz crystal
f	Operating frequency
f_p	Parallel resonant frequency
f_s	Series resonant frequency
f_{CL}	Operating frequency at certain load capacitance C_L
$F(j\omega)$	Transfer function of feedback circuit
g_m	Trans-conductance of a transistor
$g_{m(1)}$	Fundamental trans-conductance
$g_{m\ min}$	Minimum trans-conductance of a transistor
g_{mn}	Trans-conductance of NMOS transistor
$g_{mn(1)}$	Fundamental trans-conductance of NMOS transistor
g_{mp}	Trans-conductance of PMOS transistor
$g_{mp(1)}$	Fundamental trans-conductance of PMOS transistor
g_{mt}	Total trans-conductance
$g_{mt(1)}$	Total fundamental trans-conductance
i	AC current passing in quartz crystal
i_D	Large signal current passing in a transistor
i_{Dn}	Large signal current passing in NMOS transistor
i_{Dp}	Large signal current passing in PMOS transistor
$\|I\|$	AC current magnitude passing in quartz crystal
I_{ctat}	Generated CTAT current
I_{dc}	Quiescent dc current
$I_{Dn(1)}$	Fundamental component of large signal current passing in NMOS transistor
$I_{Dp(1)}$	Fundamental component of large signal current passing in PMOS transistor
$Im(Z_c)$	Imaginary part of small signal circuit impedance
I_{ptat}	Generated PTAT current
I_{ref}	Generated constant current
I_s	Reverse saturation current of a bipolar transistor
I_{ss}	Steady state current
k_B	Boltzmann constant
K	Large signal steady state point at typical conditions
K^*	Large signal steady state point at a certain corner
K_n	NMOS transistor constant multiplied by the aspect ratio
K_p	PMOS transistor constant multiplied by the aspect ratio
L	Transistor length
L_m	Motional arm inductance of quartz crystal
m	Current density ratio of bipolar emitter
p	Frequency pulling factor at typical conditions
p^*	Frequency pulling factor at a certain corner

q	Electron charge
Q	Quality factor of quartz crystal
$Re(Z_c)$	Real part of small signal circuit impedance
$Re(Z_{c(1)})$	Real part of large signal circuit impedance at fundamental frequency
R_{bias}	Bias resistance
R_m	Motional arm resistance of quartz crystal
T	Absolute temperature
T_0	Ambient absolute temperature
T_{on}	Output voltage pull up time interval
T_{period}	Periodic time
v	AC voltage across quartz crystal
V_{be}	Voltage across the p-n junction
$V_{dc\ ref}$	Reference dc voltage
V_{dd}	Positive supply voltage
V_{dn}	Drain voltage of NMOS transistor
V_{ds}	Drain source voltage difference of a transistor
V_{dsn}	Drain source voltage difference of NMOS transistor
V_{ε}	Error voltage
V_f	Feedback voltage
V_{gn}	Gate voltage of NMOS transistor
V_{gp}	Gate voltage of PMOS transistor
V_{gs}	Gate source voltage difference of a transistor
$\lvert V_{gs(1)}\rvert$	Fundamental harmonic of gate source voltage of a transistor
V_{gsn}	Gate source voltage difference of NMOS transistor
V_p	Crystal oscillator amplitude
V_{ptat}	Proportional to absolute temperature voltage
V_a	Quiescent dc voltage
V_{ref}	voltage independent of temperature
V_{sdp}	Source drain voltage difference of PMOS transistor
V_{sgp}	Source gate voltage difference of PMOS transistor
V_{sp}	Source voltage of PMOS transistor
V_{ss}	Steady state amplitude
V_{th}	Threshold voltage
V_{thn}	Threshold voltage of NMOS transistor
V_{thp}	Threshold voltage of PMOS transistor
V_T	Thermal voltage
$V_{(1)}$	The complex value of the fundamental component of v
W	Transistor width
$Z(s)$	Impedance of quartz crystal equivalent circuit
$\lvert Z(s)\rvert$	Impedance magnitude of quartz crystal equivalent circuit
Z_c	Small signal circuit impedance
Z_c^*	Small signal circuit impedance at fundamental frequency at a certain corner
$Z_{c(1)}$	Large signal circuit impedance at fundamental frequency
$Z_{c(1)}^*$	Large signal circuit impedance at fundamental frequency at a certain corner
$Z_{circuit}$	Circuit impedance
Z_m	Motional arm impedance
$Z_{resonator}$	Resonator impedance
θ	Angle of transition
ϕ	Angle of transition
Φ_A	Phase of amplifier circuit transfer function
Φ_F	Phase of feedback circuit transfer function
Δf	Frequency drift
μ_n	Electron mobility
μ_p	Hole mobility
ω	Angular frequency
ω_s	Angular series resonant frequency
ω_p	Angular parallel resonant frequency

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
AM	Amplitude Modulation
CMOS	Complementary Metal-Oxide-Semiconductor
CTAT	Complementary-To-Absolute-Temperature
CV	Capacitance Voltage
DAC	Digital Analog Converter
DFF	Delay Flip Flop
HF	High Frequency
IC	Integrated Circuit
MCXO	Microcomputer Compensated Crystal Oscillator
MIM	Metal Insulator Metal
MOS	Metal-Oxide-Semiconductor
MTI	Moving Target Indicator
NMOS	N-channel Metal-Oxide-Semiconductor
OTA	Operational Trans-conductance Amplifier
OCXO	Oven Compensated Crystal Oscillator
PMOS	P-channel Metal-Oxide-Semiconductor
PPM	Part Per Million
PTAT	Proportional-To-Absolute-Temperature
PVT	Process Voltage Temperature
RF	Radio Frequency
RbXO	Rubidium Crystal oscillator
SSB	Single Side Band
TCXO	Temperature Compensated Crystal Oscillator
TV	Television
UHF	Ultra High Frequency
VCR	Video Cassette Recorder
VHF	Very High Frequency
XO	Crystal Oscillator